EKG De-noising using 2-D Wavelet Techniques

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Abstract

The electrocardiogram (ECG or EKG) is a recording of the potential produced by the heart, taken from specific predetermined parts of the body such as arms, legs or points on the chest. It plays an important role in medical field as monitoring of human body and the diagnosis of many heart related problems depend on the recording. Hence its accurate measurement is a must.

This paper presents the study of filtering the noises present in an EKG waveform using 2-D wavelet techniques. Wavelets are mathematical functions that cut up data into different frequency components, and then study each component with a resolution matched to its scale. Wavelets are predominantly used for image processing techniques. Hence to use a 2-D technique over a 1-D signal, an EKG should be represented as a mesh or a 2-D image map. Such an image map, or an EKG map in this case, can be used by wavelet processing for de-noising purposes. The de-noising procedure is performed using three steps: decomposition, thresholding and reconstruction. The paper discusses the mentioned steps in detail.

1. Introduction to EKG

The electrocardiogram (ECG or EKG) is a graphic recording or display of the time-variant voltages produced by the myocardium during the cardiac cycle [1]. It is the physiological measurement of the cardiovascular systems. Cardiovascular system is the transport system of the body, by which food, oxygen, water and all other essentials are carried to the tissues and cells and their waste products are carried away. It comprises of blood, blood vessels (arteries, capillaries and veins), and the heart. ECG was originally observed by Waller in 1889 using his pet bulldog as the signal source and the capillary electrometer as the recording device. In 1903, Einthoven enhanced the technology by employing the string galvanometer as the recording device and using human subjects with a variety of cardiac abnormalities [2].

1.a Basic Waveform

The record of the bio-potentials generated by the muscle of the heart is the electrocardiogram and the basic waveform recorded for a normal person is shown below:

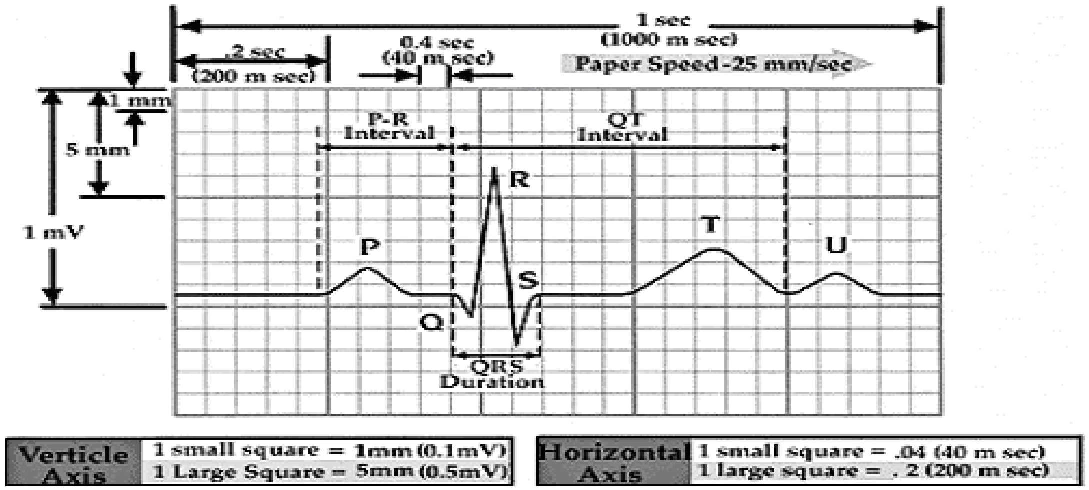

Figure 1: Electrocardiogram waveform [2]

1. b Noises in ECG

The main noises found in an ECG waveform are the common mode signals. The common mode voltage (CMV) in ECG is composed of two components:

- DC electrode offset potential
- 50 or 60 Hz ac induced interference

This 50 or 60 Hz interference also known as *Hum* interference is caused by magnetic and electric fields from power lines and transformers cutting across ECG electrodes and patients. Hum currents flow in signal, common, and ground wires via capacitive coupling between the field and the system.

1.c Surface Representation of the EKG Waveform

Thus far, we've discussed only one-dimensional data, which encompasses most ordinary signals. However, wavelet analysis can be applied to two-dimensional data (images) and, in principle, to higher dimensional data.

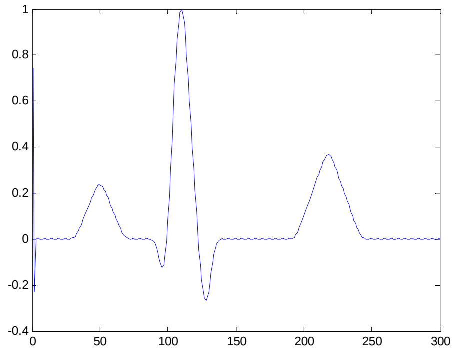

Figure 2: Typical EKG Waveform

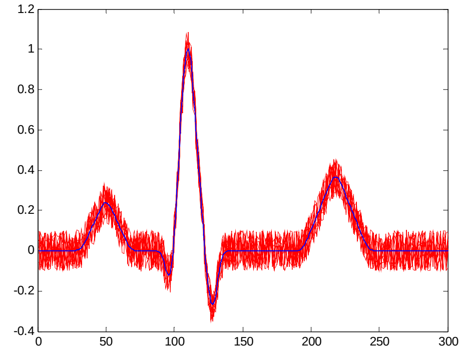

Figure 3: EKG waveform with added noise

In the case of an Image the x and y coordinates are the pixel numbers and the z coordinate represents either the grayscale or color intensity level. The EKG map has the x and y axes as time and frame number, and the z-axis is the signal strength. This EKG map can now be used as input to image filtering/de-noising algorithms.

Each EKG has different noise but the overall characteristics are shared by all the constituent EKG frames in the noisy EKG map. As seen in the figure below, each EKG signal has different noise levels yet the overall EKG reflects the gradual trend in the noise levels. The noise can component can be seen in the top view as stripes of white in the background colors.

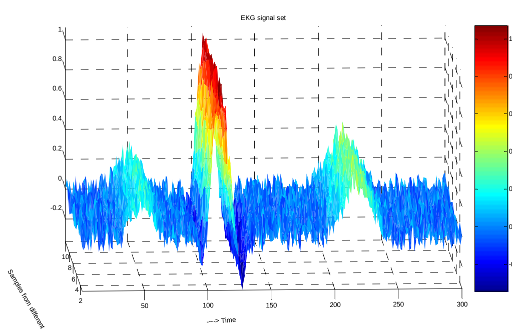

Figure 4: EKG map using 10 EKG frames

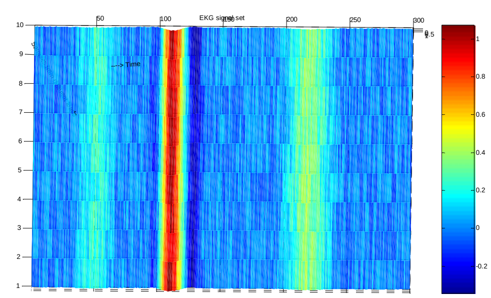

Figure 5: Surface view of the EKG map

2. Wavelets

A wavelet is a waveform of effectively limited duration that has an average value of zero. The concept of wavelets developed when the attention of researchers gradually turned from frequency-based analysis to scale-based analysis and when it started to become clear that an approach measuring average fluctuations at different scales might prove less sensitive to noise. The present theoretical form of wavelet concept was first proposed by Jean Morlet and the team at the Marseille Theoretical Physics Center working under Alex Grossmann in France.

2. a Wavelet Analysis

Wavelet analysis represents a windowing technique with variable-sized regions. Wavelet analysis allows the use of long time intervals where we want more precise low-frequency information, and shorter regions where we want high-frequency information.

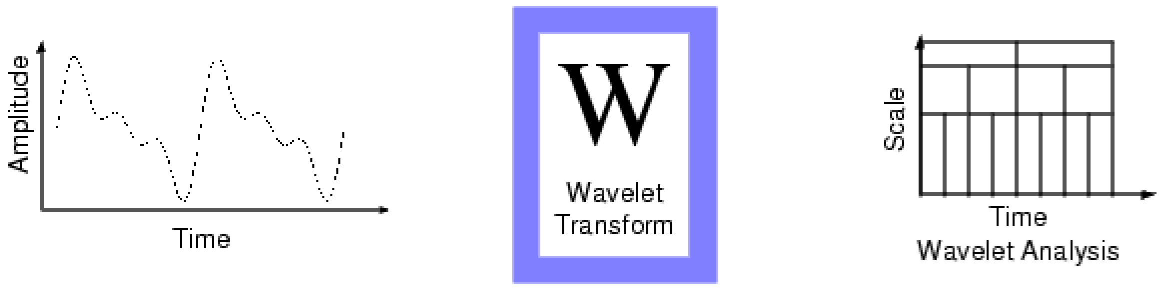

Figure 6: Wavelet transform [3]

The wavelet analysis does not use a time-frequency region, but rather a time-*scale* region. A major advantage afforded by wavelets is the ability to perform *local analysis* -- that is, to analyze a localized area of a larger signal. Wavelet analysis is capable of revealing aspects of data that other signal analysis techniques miss, aspects like trends, breakdown points, discontinuities in higher derivatives, and self-similarity. Furthermore, because it affords a different view of data than those presented by traditional techniques, wavelet analysis can often compress or de-noise a signal without appreciable degradation.

3. 2-Dimensional De-noising using Wavelets

This section describes the image de-noising algorithm, which achieves near optimal soft threshholding in the wavelet domain for recovering original signal from the noisy one.

De-noising is one of the most important applications of wavelets. The underlying concept of de-noising in images is similar to the 1D case. The goal is to remove the noise while retaining the important signal features as much as possible. The algorithm is very simple to implement and computationally more efficient.

The noisy image is represented as a two dimensional matrix

X (i,j) = 1 to N.
The noisy version of the image is modeled as

Y (i,j) = X (i,j) + No (i,j); where i, j = 1 to N and No is the noise function

We can use the same principles of thresholding and shrinkage to achieve de-noising as in 1-D signals. The problem again boils down to finding an optimal threshold such that the mean squared error between the signal and its estimate is minimized.

The wavelet decomposition of an image is done as follows: In the first level of decomposition, the image is split into 4 sub-bands, namely the HH, HL, LH and LL sub-bands [4].

- The HH sub-band represents the diagonal details of the image;
- The HL sub-band represents the horizontal features
- The LH sub-band represents the vertical structures.
- The LL sub-band is the low resolution residual consisting of low frequency components and this sub-band is further split at higher levels of decomposition.

The de-noising procedure is performed using three steps:

1) **Decomposition**: Choose a wavelet and a level of decomposition N, and then compute the wavelet decompositions of the signals at level N. The signal is decomposed into N levels.

2) **Thresholding**: For each level from 1 to N and for each signal, a threshold is selected and thresholding is applied to the detail coefficients.

3) **Reconstruction**: Compute wavelet reconstructions using the original approximation coefficients of level N and the modified detail coefficients of levels from 1 to N.

4. Results

Threshold determination is an important question while de-noising. A small threshold may yield a result close to the input, but the result may still be noisy. A large threshold on the other hand, produces a signal with a large number of zero coefficients. This leads to a smooth signal. Paying too much attention to smoothness, however, destroys details and in image processing may cause blur and artifacts.

We implemented de-noising by applying different wavelets such as the haar, mexican hat each with varying levels of de-composition. Best results were obtained using the ‘sym6’ wavelet with 4 level decomposition and soft thresholding.

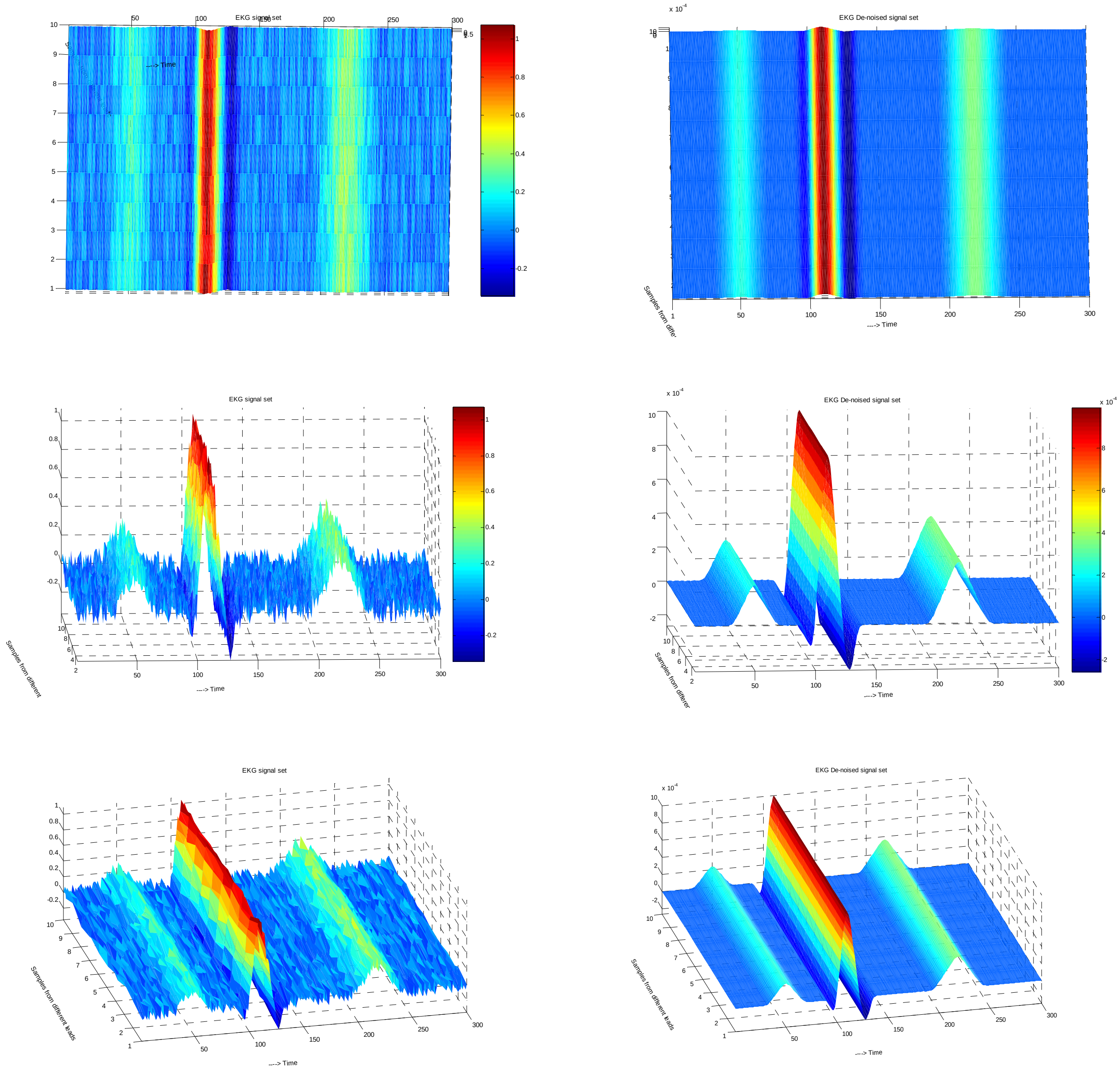

Figure 6: Comparison between the noise EKG map and the De-nosied EKG map

4. Conclusion

In this paper we have present an approach to implement 2-dimensional image de-noising techniques on 1-dimensional EKG signal by constructing a EKG map using multiple samples of the EKG waveform. Wavelet de-nosing is easy to implement and tune suiting to the application. Multiple wavelets were applied with different levels of decomposing and thresholding. The best results obtained using sym6 wavelet is presented in this paper.

References

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Biographies

Manan Joshi has received his MS degree in Electrical Engineering from University of Bridgeport in Dec 2006. Currently he is pursuing his PhD in Computer Science & Engineering at the University of Bridgeport. His research interests are in the field of Analog Electronics, Medical Electronics, Computer Networking and Wireless Communications.

Sarosh Patel received the B.E. degree in Electrical and Electronics Engineering with Distinction from the Faculty of Engineering Osmania University, India in 2002, and M.S. degrees in Electrical Engineering and Technology Management from the School of Engineering, University of Bridgeport (UB), in 2006.He is currently pursuing Ph.D. in Computer Engineering at U.B. He currently works as a Research Assistant at the Interdisciplinary RISC (Robotics and Intelligent Systems Control) Lab. He had been nominated for inclusion in 2005 & 2006 edition of Who's Who Among Students in American Universities and has been elected to the Phi Kappa Phi honor society.

Lawrence V. Hmurcik is Professor and Chairman of Electrical Engineering at the University of Bridgeport, Bridgeport, CT. He earned his Ph.D. in semiconductor devices at Clarkson University in 1980. He worked in Diamond Shamrock's research division for 3 years before joining the University of Bridgeport in 1983. Dr. Hmurcik has 50 publications and 5 grants. He is also a professional consultant with 240 case entries, including 14 appearances in Court and Legal Depositions. Dr. Hmurcik's interests have changed over the years: starting in Solar Cell technology in 1977, Dr. Hmurcik is currently pursuing work in Medical Electronics and Electric Safety.